Western Low-Rank Coal Development Analysis

G.H. Gronhovd and E.A. Sondreal

U.S. Department of Energy, Grand Forks Energy Technology Center
Box 8213, University Station
Grand Forks, North Dakota 58202

J.A. Kotowski and G.A. Wiltsee

Energy Resources Co. Inc., 1148 Alpine Road, Suite B
Walnut Creek, California 94596

Introduction

An analysis of the technical, environmental, and economic constraints to expanded development of the U.S. low-rank coal resource is in progress. The primary objective of the study is to propose a comprehensive national R&D program focusing on technology development for enhanced utilization of lignite and subbituminous coal. Utilization of these fuels has expanded rapidly in recent years and will continue to expand in line with national energy priorities. This will require technological improvements and developments to solve unique problems associated with the physical and chemical properties of low-rank coals. These properties include high moisture content, dispersed alkaline mineral matter content, high reactivity, and low sulfur content. The majority of coal R&D programs in this country are oriented towards bituminous coal, which exhibits significantly different behavior in most extraction, combustion, and conversion processes.

The study is being directed by the Grand Forks Energy Technology Center (GFETC), which has the lead mission within the Department of Energy for technology "applications for low-rank coals." To fulfill this assignment, GFETC must:

1. Identify the properties of low-rank coals that affect the applicability and economics of technologies;

2. Identify R&D needs unique to low-rank coals, and establish priorities based on potential impact on expanded development; and

3. Ensure that DOE's coal R&D programs address those needs.

Historically, GFETC has focused on lignite R&D, primarily on Northern Great Plains lignite. This has included programs in coal combustion, preparation, liquefaction, gasification, and environmental control technologies. The Center has also sponsored a biennial lignite Symposium, designed to encourage the transfer of low-rank coal technology data between government, industry, and academia (1,2). The present study was initiated as a means to identify other needed R&D areas associated with the whole spectrum of U.S. low-rank coals.

As a result, the scope of the study is broad, encompassing all of the major lignite and subbituminous coal deposits in this country, and including some attention to peat as well. The technical analysis includes assessment of resources; technologies, from extraction through final utilization (including environmental control); and regulatory, environmental impact, and market factors. The R&D requirements definition will be based on these assessments plus a review of current R&D programs, costs, and impacts.

Study Approach

The study approach is summarized in Table 1, which shows the eight major tasks or areas of investigation. As a rough indicator of the relative emphasis being placed on these various tasks, the percentage of the total contract funding allocated to each task is indicated on the table.

The initial task, labelled "Development Scenarios," includes a literature review, definition of key issues and analytical methodologies, and establishment of the study's data base. In Task 2, the U.S. low-rank coal resources are being defined in terms of their occurence, quantity, quality, characteristics, and physical/chemical properties. An effort is being made to classify the resources according to their behavior in various utilization processes, which influences their development potential. This effort is closely tied to Task 3, the technology evaluation. A comprehensive list of technologies applicable to low-rank coals is being evaluated to ensure that the resulting preliminary R&D "wish list" is as exhaustive as possible.

Table 1
Major Tasks in the Low-Rank Coal Study

1. Low-Rank Coal Development Scenarios (6%)
   - 1.1 Literature Review
   - 1.2 Technology Definitions
   - 1.3 Regulatory/Environmental/Market Definitions
   - 1.4 Low-Rank Coal Data Base

2. Resource Characterization (8%)
   - 2.1 Occurrence
   - 2.2 Properties/Characteristics
   - 2.3 Classification

3. Technology Evaluation (42%)
   - 3.1 Extraction
   - 3.2 Transportation Systems
   - 3.3 Preparation and Storage
   - 3.4 Processing and Utilization
   - 3.5 Environmental Control Technology

4. Regulatory Requirements/Constraints (4%)
   - 4.1 Definition
   - 4.2 Roadmap
   - 4.3 Effects on Development

5. Environmental Impact Analysis (3%)
   - 5.1 Land Use/Reclamation
   - 5.2 Air Quality
   - 5.3 Water Quality
   - 5.4 Ecological Effects
   - 5.5 Socio-Economic Effects

6. Market Analysis (6%)
   - 6.1 Existing Markets and Penetration
   - 6.2 Potential Markets

7. RD&D Program Evaluation (11%)
   - 7.1 Definition and Priorities
   - 7.2 Review of Current RD&D Programs
   - 7.3 Cost and Impact Analysis

8. Task Force Utilization (20%)
   - 8.1 Development Scenarios Evaluation
   - 8.2 Technical Analysis Evaluation
   - 8.3 RD&D Program Definition
   - 8.4 RD&D Program Impacts and Recommendations

In addition to these purely technical considerations, there are various social, economic, and environmental factors in the regions containing low-rank coals that will affect the development of these resources. These factors are the subject of Tasks 4, 5, and 6. Each of these analyses is being conducted on a regional basis, with detailed calculations being made for a few carefully selected examples, in contrast to the more comprehensive approach being utilized in Tasks 2 and 3.

In Task 7, we will define and establish priorities for the R&D activities necessary to stimulate the effective development and utilization of low-rank coals in this country. This will be done in light of the present related governmental and industrial research and development efforts, and will include a preliminary analysis of costs and impacts of the proposed program. The practical difficulties of evaluating and ranking R&D projects, even when the most rigorous decision/analytical techniques are used, are great but do not diminish the need for this type of exercise.

Because of the scope and difficulty of the effort, we have enlisted a task force of recognized experts on the technical and regional issues germane to the study to meet with the study team at four critical points. At the periodic formal review meetings, interim results are discussed and decisions are made regarding emphasis, priorities, and methodologies for the analysis. In particular, the task force will participate actively in the development of R&D recommendations. This task force utilization effort is listed on Table 1 as Task 8.

The schedule for the study is June 1979 through June 1980, and is such that preliminary R&D recommendations will be in the formulation stage at the time of the American Chemical Society meeting in late March. The authors expect to summarize some of the key conclusions and recommendations of the study at that time. It is not possible to do so in this preprint because the work is in progress. Therefore, the remainder of this paper provides some preliminary findings and background information on some of the study areas.

Occurrence and Properties of Low-Rank Coals

The locations of the major lignite and subbituminous coal deposits in the U.S. are shown in Figure 1, and the magnitude of the resources contained in the largest low-rank coal-bearing regions is indicated in Table 2. The two major lignite-bearing areas are the Fort Union Region and the Gulf Coast Lignite Region, with the predominant surface-minable reserves being in the states of North Dakota, Montana, and Texas. The largest subbituminous coal deposits are in the Powder River Region of Montana and Wyoming, the San Juan Basin of New Mexico, and in Northern Alaska. Whether one considers the total identified resources (over one trillion tons) or just the strippable reserve base (over 100 billion tons), the potential supply of energy from low-rank coals is enormous.

Figure 1
United States Low-Rank Coal Resources

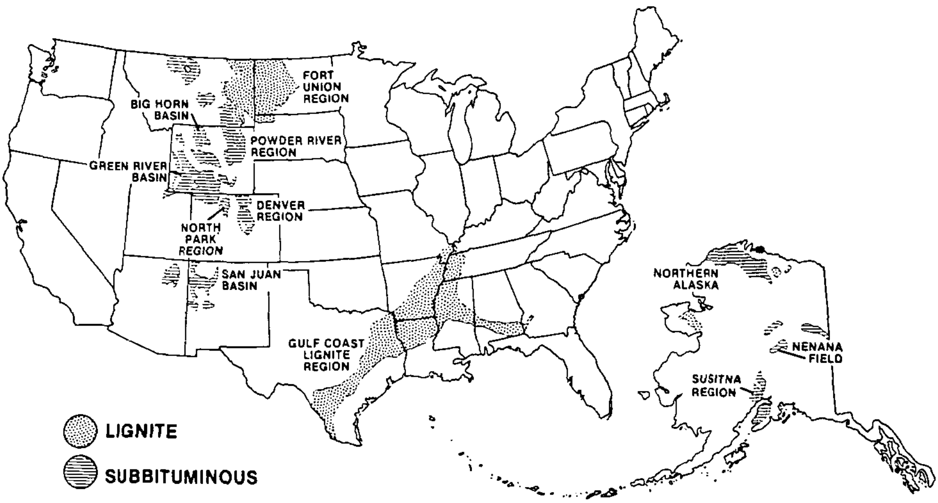

Figure 2
New Source Performance Standards for SO_2 Emissions from Electric Utility Steam Generators

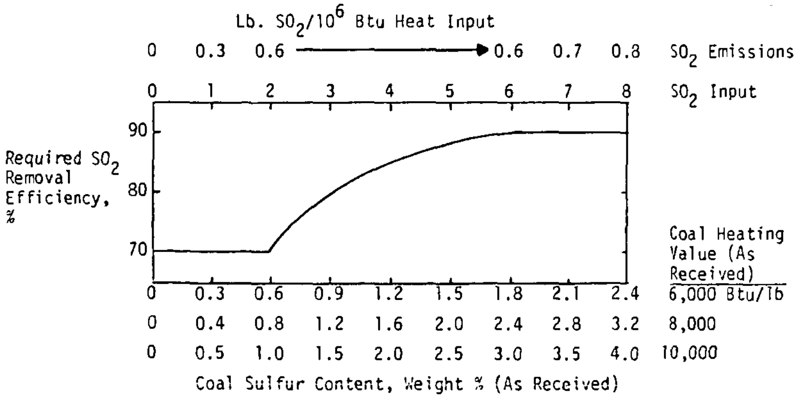

Table 2
Major United States Low-Rank Coal Regions

Region	Predominant Coal Rank	Identified Resources, Billion Short Tons	Strippable Reserve Base, Billion Short Tons
Fort Union Region	Lignite	465.3	31.9
Powder River Region	Subbituminous	238.1	57.5
San Juan Basin	Subbituminous	50.6	1.8
Northern Alaska	Subbituminous	100.9	5.0
Gulf Coast Lignite	Lignite	68.3	11.6
Others (see Fig. 1)	Subbituminous, some Lignite	165.2	0.9
		1,088.4	108.7

Sources: References 3-9

The distinguishing properties of low-rank coals are derived from their fundamental composition. Coals are complex aggregations of physically distinctive and chemically different organic materials (macerals) and inorganic materials (minerals). Strictly speaking, the rank of coal expresses only the degree to which geologic alteration processes (metamorphism) have affected the properties of the organic substances. In this sense, rank classification is independent of inorganic content; nevertheless, U.S. low-rank coals do exhibit characteristic differences from high-rank coals in their mineral matter content and therefore in their ash properties. This is apparently a coincidental or indirect relationship caused by the respective geologic ages and geographic locations of the U.S. low-rank coals and high-rank coals (10,11).

Some important properties of the organic and inorganic fractions of U.S. coals are summarized in Table 3. The data on organic content are based on samples of essentially pure vitrinite, which is the predominant maceral in U.S. coals (10). All of the properties listed have an impact on the coal's behavior in extraction, utilization, or conversion processes; the most noticeable properties are the high inherent moisture and oxygen contents of low-rank coal macerals, and their corresponding low heating values.

The data on mineral matter content are reported as ash, which is the residue left after complete incineration of the combustible constituents. The ash compounds are reported as oxides; however, they may actually occur as a mixture of silicates, oxides, and sulfates (11). Due to the wide variations in coal ash composition, the data are presented as ranges. A notable trend is the higher proportion of the alkali components CaO, MgO, and Na_2O in low-rank coals. The acidic components SiO_2 and Al_2O_3 are more prominent in the higher rank coals. The generally higher proportions of SO_3 in low-rank coal ash reflect the high retention of coal sulfur by the alkaline ash, which averages 78% for lignites, 26% for subbituminous coal, and 10% for the generally higher sulfur bituminous coals (11).

Table 3
Selected Analyses of U.S. Coals of Different Ranks

Organic Content (Vitrinite Samples)		Lignite	Subbituminous	Bituminous	Anthracite
Moisture Capacity, Wt.%		40	25	10	< 5
Carbon, Wt.% DMMF*		69	74.6	83	94
Hydrogen, Wt.% DMMF		5.0	5.1	5.5	3.0
Oxygen, Wt.% DMMF		24	18.5	10	2.5
Vol. Mat., Wt.% DMMF		53	48	38	6
Aromatic C/Total C		0.7	0.78	0.84	1.0
Density (He, g/cc)		1.43	1.39	1.30	1.5
Grindability (Hardgrove)		48	51	61	40
Btu/lb, DMMF		11,600	12,700	14,700	15,200
Inorganic Content (Weight % of Total ASTM Ash)					
Acidic Components	SiO_2	6-40	17-58	7-68	48-68
Acidic Components	Al_2O_3	4-26	4-35	4-39	25-44
Acidic Components	Fe_2O_3	1-34	3-19	2-44	2-10
Acidic Components	TiO_2	.0-.8	.6-2	.5-4	1-2
	P_2O_5	.0-1	.0-3	.0-3	.1-4
Alkali Components	CaO	12.4-52	2.2-52	.7-36	.2-4
Alkali Components	MgO	2.8-14	.5-8	.1-4	.2-1
Alkali Components	Na_2O	.2-28	-	.2-3	-
Alkali Components	K_2O	.1-1.3	-	.2-4	-
	SO_3	8.3-32	3.0-16	.1-32	0.1-1

*Dry, mineral-matter-free basis.

Sources: References 10 and 11

These mineral matter properties of U.S. low-rank coals have wide-ranging effects, such as: 1) high fouling rates on boiler tubes, primarily linked to high sodium content; 2) high fly ash resistivity, thus relatively poor ESP performance; 3) unique opportunities for sulfur removal, such as ash-alkali wet scrubbing, dry scrubbing, and ash recirculation in fluid bed combustors; and 4) catalytic effects on certain reactions such as coal hydrogenation (liquefaction).

One additional characteristic of U.S. low-rank coal is its typically low sulfur content, as shown in Table 4. When these percentages are converted from a dry to an as-mined basis, about 90 percent of the reserve base of U.S. low-rank coal is shown to have less than one percent sulfur (13).

Table 4
Distribution of U.S. Low-Rank Coal Reserve Base by Sulfur Content

Sulfur Content, % (Dry Basis)	1.0 or Less	1.1-1.8	1.8-3.0	Over 3.0	Total
Subbituminous	89.5	8.1	2.0	0.4	100.0
Lignite	40.7	33.4	23.4	2.5	100.0

Source: Reference 12

Utilization and Processes

Present use of low-rank coal is concentrated in electric utility steam generating units fed by surface-mined coal. This conventional application of the resource is experiencing rapid change. As the data in Table 5 indicate, existing small stoker and cyclone-fired units have given way to very large pulverized-coal-fired, dry bottom furnaces. All of the new plants will incorporate SO_2 removal systems as mandated by the recently issued New Source Performance Standards (see Figure 2). The same regulation also requires highly effective particulate removal systems, and combustion system modifications to meet NOx emission limits, in all new or modified electric utility steam generating units larger than about 25 MWe (250 million Btu/hr. input).

The dominating near-term R&D issues for low-rank coals revolve around the environmental control technologies that are being developed to meet these requirements. In the area of SO_2 control, the variable percentage removal requirement shown in Figure 2 (which translates to a 70% removal requirement for the majority of low-rank coals) was instituted for the express purpose of encouraging the further development of dry scrubbing techniques for low- and medium-sulfur coals (14). The combined stack gas cleaning strategy of dry SO_2 scrubbing plus the use of baghouses for particulate removal has a number of apparent advantages over today's wet scrubber/ESP systems, and appears to be strongly encouraged by the NSPS. However, the lack of operational experience with such systems provides ample opportunity for well-directed R&D. Wet scrubbers (particularly ash-alkali systems for low-rank coals) and electrostatic precipitators (combined with novel conditioning or removal devices) will both continue to have applications for specific coals; however, many problems relating to enhanced removal efficiencies, sludge disposal, sulfate and sulfuric acid mist carryover, and trace element emissions, remain to be solved. Potential operating problems associated with combustion modifications for NOx control also need R&D. Finally, the task of integrating the study of these interrelated problems and opportunities through a systems engineering approach is just beginning, for example in the EPRI Arapahoe program (15).

Ash fouling of boiler tubes continues to be a major problem encountered in burning lignites and subbituminous coals. Sodium content has been identified as the most important of a number of factors that contribute to the fouling problem. The possible control methods to decrease chances of fouling include: 1) boiler designs involving low volume heat release and low furnace exit temperature; 2) restrictions on the sodium level in the coal by selective mining, blending and upgrading, 3) the use of additives; and 4) possibly the use of overfire air with fuel-rich burners (16).

Table 5
U.S. Low-Rank Coal-Fired Electric Power Plants

Fuel	Lignite				Subbituminous Coal			
Location	Fort Union Reg.		Texas		West		Midwest	
Plants, Capacity	No.	MWe	No.	MWe	No.	MWe	No.	MWe
Operating Plants (1979)	19	3,357	11	5,660	20	7,389	79	10,627
Furnace: PC	8	1,614	11	5,660	20	7,389	58	6,705
Stoker	7	205	-	- -	-	- -	9	97
Cyclone	4	1,538	-	- -	-	- -	7	1,265
Unknown	-	- -	-	- -	-	- -	5	2,560
Wet Scrubber:								
Limestone	5	1,720	5	3,575	12	3,783	10	3,477
Ash-Alkali	2	670	-	- -	-	- -	4	2,116
Spray Dryer	2	716	-	- -	-	- -	-	- -
Particulate Removal:								
ESP	16	3,329	11	5,660	17	7,192	48	7,131
Baghouse	-	- -	2	1,150	-	- -	8	1,788
Mechanical	5	210	-	- -	2	230	21	518
Unknown	7	72	-	- -	-	- -	5	1,929
Plants Under Construction and Announced	6	1,947	18	10,390	5	1,349	34	15,372
Furnace: PC	6	1,997	9	5,175	4	1,249	2	1,100
Stoker	-	- -	-	- -	-	- -	6	107
Cyclone	-	- -	-	- -	1	100	1	200
Unknown	2	1,050	9	5,215	-	- -	25	13,004
Wet Scrubber:								
Limestone	-	- -	8	4,600	-	- -	1	800
Ash-Alkali	-	1,100	-	- -	-	- -	5	3,100
Spray Dryer	2	880	-	- -	1	330	-	- -
Particulate Removal:								
ESP	-	- -	9	5,175	2	450	-	- -
Baghouse	-	- -	-	- -	1	350	-	- -
Mechanical	-	- -	-	- -	-	- -	3	18
Unknown, ECT	1	410	14	8,675	2	589	31	15,934

Numerous advanced technologies are being pursued in a wide range of government and industry R&D programs. Many of these technologies will contribute to enhanced utilization of low-rank coals in the future. Extraction of the abundant thick, deep coal seams in the western U.S. will eventually be pursued. A variety of techniques, including advanced longwall and in situ conversion systems (such as underground coal gasification), are currently being researched.

Coal cleaning and preparation techniques have historically not been applied to U.S. low-rank coals because of cost considerations and the relatively low ash content of the coals. The fact that most of the mineral matter in low-rank coals tends to be highly dispersed and/or organically bound means that typically only 15-30% of the mineral matter is separable in a carbon tetrachloride float-sink separation (17). Lignite is characterized by high moisture content which is also bound in the coal structure. Upon drying, the structure of low-rank coal tends to change and to produce smaller, friable particles which may be either highly oxidized (when air-dried) or highly reactive (when inert-dried) (18). Nevertheless, wider geographic marketability and improved over-all process economics could potentially be achieved if energy-efficient techniques for selective removal of moisture or mineral matter were developed.

Fluidized-bed combustion (FBC) systems are receiving major emphasis as the potential next generation of industry, and possibly utility, boilers. Almost all major projects are utilizing bituminous coal. The technology has a good apparent fit with low-rank coals because of their inherent sulfur absorption capability. A particularly promising market appears to be developing in Texas, which has a high concentration of industry fuel users juxtaposed with large lignite deposits. Some of the FBC research needs specific to low-rank coals include selection of bed materials, use of ash recycle, control of ash agglomeration, and possible corrosion/erosion problems.

In the highly visible synfuels area, none of the major developing U.S. processes for liquefaction or gasification appears to be optimized or tailored to the unique properties of low-rank coals, with the possible exception of the CO_2 Acceptor gasification process. Low-rank coals are well suited for fixed-bed gasification because they do not agglomerate or cake when heated. The high inherent moisture content of low-rank coal has a variety of effects on gasification processes. Plant water requirements may be lower if coal moisture is recovered. High moisture, however, can cause heat balance problems and pre-drying of the coal can produce an excessive amount of fines which cannot be included in feed for fixed-bed reactors. Large volumes of gas liquor may be produced, affecting waste water treatment requirements. These factors, plus the reactive nature of low-rank coals and the presence of catalytically active mineral matter, justify the need for development of low-rank coal specific processes (19).

Coal liquefaction processes also need to be adapted to special problems posed by low-rank coals. The high content of functional groups (particularly oxygen) affects liquefaction chemistry. Low-rank coals react very rapidly with carbon monoxide providing the basis for development of processes using synthesis gas instead of more expensive hydrogen. High moisture content adds to reactor pressure. Drying can deactivate the coal because of surface oxidation and collapse of the pore structure (20). The special forms of low-rank coal mineral matter may catalyze liquefaction reactions; they can also lead to formation of calcium carbonate deposits in the reactors. Viscosity of the distillation bottoms is higher for low-rank coals, which affects process design and operability (21). All of these factors affect the optimization of recycle solvent composition and product separation techniques, which are important research areas for liquefaction processes in general.

REFERENCES

1. Proceedings of the Tenth Biennial Lignite Symposium, Sponsored by the U.S. DOE Grand Forks Energy Technology Center, and the University of North Dakota, Grand Forks, N.D., May 30-31, 1979.

2. Proceedings of the Ninth Biennial Lignite Symposium, Sponsored by the U.S. DOE Grand Forks Energy Technology Center, and the University of North Dakota, Grand Forks, N.D., May 18-19, 1977.

3. 1979 Keystone Coal Industry Manual, McGraw-Hill Mining Publ., New York, N.Y., 1979.

4. Demonstrated Coal Reserve Base of the U.S. on January 1, 1976, USBM Mineral Industry Survey.

5. Glass, G.B., Wyoming Coal Fields, 1978, Geological Survey of Wyoming, Public Info. Circular 9, 1978, 91 pp.

6. Clardy, B.F., Arkansas Lignite Investigations, Preliminary Report, Arkansas Geological Commission, 1979, 133 pp.

7. Roland, H.L., Jr., Lignite - Evaluation of Near-Surface Deposits in NW Louisiana, Louisiana Geological Survey Mineral Resources Bulletin No. 2, 1976.

8. Averitt, P., Coal Resources of the United States, January 1, 1974, USGS Bulletin 1412, 1975, 121 pp.

9. Combo, J.X. and others, Coal Resources of Montana, USGS Circular 53, 1949.

10. Neavel, R.C., Coal Structure and Coal Science: Overview and Recommendations, presented at the ACS Symposium on Coal Structure, Honolulu, Hawaii, April 2-6, 1978, ACS, Div. of Fuel Chem. Preprints, v. 24, No. 1, pp. 73-77

11. Sondreal, E.A., W.R. Kube, and J.L. Elder, Analysis of the Northern Great Plains Province Lignites and their Ash: A Study of Variability, USBM RI 7158, 1968, 94 pp.

12. Hamilton, P.A., D.H. White, Jr., and T.K. Matson, The Reserve Base of U.S. Coals by Sulfur Content; Part 2, The Western States, BuMines IC8693, 1975, 322 pp.

13. Selle, S.J., F.I. Honea, and E.A. Sondreal, Direct Use of Lignite for Power Generation, presented at IGT Symposium on New Fuels and Advances in Combustion Technology, Chicago, Illinois, March 26-30, 1979, 24 pp.

14. Environmental Protection Agency, New Stationary Sources Performance Standards; Electric Utility Steam Generating Units, Federal Register v. 44, No. 113, June 11, 1979, 45 pp.

15. Giovanni, D., Integrated Environmental Control, Fossil Fuels and Advanced Systems Division R&D Status Report, EPRI Journal, May 1979, v. 4, No. 4, pp. 41-46

16. Honea, F.I., S.J. Selle, and E.A. Sondreal, Factors Affecting Boiler Tube Fouling from Western and Gulf Coast Lignites and Subbituminous Coals, presented at NACE Corrosion/79 Symposium, Atlanta, Georgia, March 12-16, 1979, 30 pp.

17. Sondreal, E.A., P.H. Tufte, and Willis Beckering. Ash Fouling in the Combustion of Low-Rank Western U.S. Coals. Combustion Sci. and Tech., v. 16, 1977, pp. 95-110

18. Oppelt, W.H., W.R. Kube, and T.W. Kamps. Drying North Dakota Lignite to 1,500 Pounds Pressure by the Fleissner Process. BuMines R.I. 5527, 1959, 30 pp.

19. Ellman, R.C., L.E. Paulson, and D.R. Hajicek, Slagging Fixed-Bed Gasification Project Status at the Grand Forks Energy Technology Center, presented at the Tenth Biennial Lignite Symposium, Sponsored by the U.S. DOE Grand Forks Energy Technology Center and the University of North Dakota, Grand Forks, N.D., May 30-31, 1979.

20. Willson, W.G., C.L. Knudson, G.G. Baker, T.C. Owens, and D.E. Severson, Application of Liquefaction Processes to Low Rank Coals. Presented at the Tenth Biennial Lignite Symposium, Sponsored by the U.S. DOE Grand Forks Energy Technology Center and the University of North Dakota, Grand Forks, N.D., May 30-31, 1979.

21. Mitchell, W.N., K.L. Trachte, and S. Zaczepinski, Performance of Low-Rank Coals in the Exxon Donor Solvent Process, presented at the Tenth Biennial Lignite Symposium, Sponsored by the U.S. DOE Grand Forks Energy Technology Center and the University of North Dakota, Grand Forks, N.D., May 30-31, 1979.